NIST NCSTAR 2

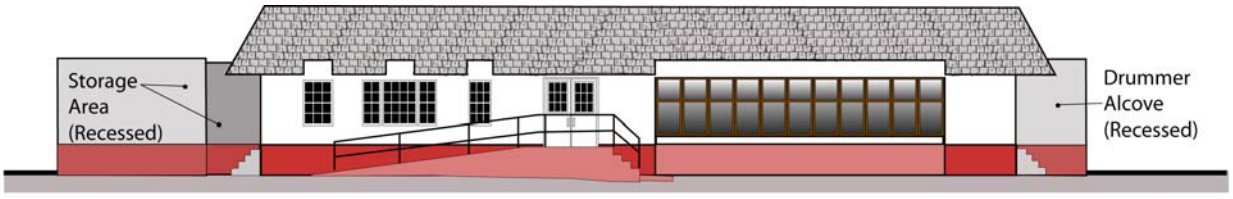
Draft Report of the Technical Investigation of The Station Nightclub Fire

William L. Grosshandler

Nelson Bryner

Daniel Madrzykowski

Kenneth Kuntz



National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

DRAFT

NIST NCSTAR 2

Draft Report of the Technical Investigation of The Station Nightclub Fire

William L. Grosshandler
Nelson Bryner
Daniel Madrzykowski
Fire Research Division
Building and Fire Research Laboratory
National Institute of Standards and Technology

Kenneth Kuntz
Federal Emergency Management Agency
U.S. Department of Homeland Security

March 2005

U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

Technology Administration
Phillip J. Bond, Under Secretary for Technology

National Institute of Standards and Technology
Hratch Semerjian, Acting Director

Disclaimer

Certain commercial entities, equipment, products, or materials are identified in this document in order to describe a procedure or concept adequately or to trace the history of the procedures and practices used. Such identification is not intended to imply recommendation, endorsement, or implication that the entities, products, materials, or equipment are necessarily the best available for the purpose.

Disclaimer

The policy of NIST is to use the International System of Units (metric units) in all publications. In this document, however, units are presented in metric units or the inch-pound system, whichever is prevalent to the discipline. Conversion tables are provided in an appendix to this report.

Disclaimer

The NIST-led investigation of The Station Nightclub fire was conducted during the same time period as civil and criminal legal actions involving the same incident, which limited the Team's access to physical evidence and the ability to interview many witnesses.

Use in Legal Proceedings

No part of any report resulting from a NIST investigation can be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a; as amended by P.L. 107-231).

National Institute of Standards and Technology NCST Act Report (NCSTAR) 2
Natl. Inst. of Std. NCST Act Rept. 2, XXX pages (March 2005)
CODEN: NSPUE2

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 2005

For sale by the Superintendent of Documents, U.S. Government Printing Office
Internet: bookstore.gpo.gov — Phone: (202) 512-1800 — Fax: (202) 512-2250
Mail: Stop SSOP, Washington, DC 20402-0001

ABSTRACT

A fire occurred on the night of Feb. 20, 2003, in The Station nightclub at 211 Cowesett Avenue, West Warwick, Rhode Island. A band that was on the platform that night, during its performance, used pyrotechnics that ignited polyurethane foam insulation lining the walls and ceiling of the platform. The fire spread quickly along the ceiling area over the dance floor. Smoke was visible in the exit doorways in a little more than one minute, and flames were observed breaking through a portion of the roof in less than five minutes. Egress from the nightclub, which was not equipped with sprinklers, was hampered by crowding at the main entrance to the building. One hundred people lost their lives in the fire. On Feb. 27, 2003, under the authority of the National Construction Safety Team (NCST) Act, the National Institute of Standards and Technology (NIST) established a National Construction Safety Team to determine the likely technical cause or causes of the building failure that led to the high number of casualties in that fire. This report documents the procedures, findings, and issues raised by the investigation. Twelve recommendations to improve model building and fire codes, standards and practices as they apply to nightclubs (as they existed in February 2003) resulted from the investigation, including (a) strengthening the requirements for the installation of automatic fire sprinklers, (b) increasing the factor of safety on the time for occupants to egress, (c) tightening the restriction on the application of flexible polyurethane foam as a finish product, (d) further limiting the use of pyrotechnics, (e) eliminating the practice of grandfathering buildings from complying with new life safety requirements, (f) requiring redundancy in the passive and active fire protection system, and (g) conducting research in specific areas to underpin the recommended changes.

Note: This version of the report is a draft for public comment.

Keywords: fire investigation, NCST, nightclub fire, sprinklers, egress, fire spread, polyurethane foam, fire modeling

TABLE OF CONTENTS

LIST OF ACRONYMS, ABBREVIATIONS AND UNITS

AHJ	Authority Having Jurisdiction
AIA	American Insurance Association
ALS	Advanced Life Safety
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATF	Bureau of Alcohol, Tobacco and Firearms
BBC	Basic Building Code
BCMC	Board for the Coordination of Model Codes
BFPC	Basic Fire Prevention Code
BLS	Basic Life Safety
BOCA	Building Officials and Code Administrators (previously Building Officials Conference of America)
CFD	computational fluid dynamics
DHS	Department of Homeland Security
FDS	Fire Dynamics Simulator
FEMA	Federal Emergency Management Agency
FPC	Fire Prevention Code
FR	fire retarded
HRR	heat release rate
IBC	International Building Code
ICC	International Code Council
IEBC	International Existing Building Code
IFC	International Fire Code
IR	infrared
ISO	International Organization for Standardization
LCL_0	lethal concentration, low
LSF	life safety feature

NCST	National Construction Safety Team
NBC	National Building Code
NFC	National Fire Code
NFPA	National Fire Protection Association
NFR	non-flame retarded
NIOSH	National Institute of Occupational Safety and Health
NIST	National Institute of Standards and Technology
ODP	Office of Domestic Preparedness
OSHA	U.S. Occupational Safety and Health Administration
PUF	polyurethane foam
RI	Rhode Island
SBC	Standard Building Code
SNEFEAP	Southern New England Fire Emergency Assistance Plan
TC	thermocouple
TIA	Technical Interim Amendment
UFC	Uniform Fire Code
USC	United States Code
USFA	United States Fire Administration
WFD	Warwick Fire Department
WWFD	West Warwick Fire Department

Units

°C	degrees Celsius
°F	degrees Fahrenheit
ft	feet
gpm	gallons/minute
in	inch
kg	kilogram
kW	kilowatt
L	liter
m	meter
mm	millimeter

min	minute
MW	megawatt
psi	pounds/in^2
s	second
W	Watt
μm	micrometer

PREFACE

On Feb. 27, 2003, under the authority of the National Construction Safety Team (NCST) Act, the National Institute of Standards and Technology (NIST) established a Team to determine the likely technical cause or causes of the building failure that led to a high number of casualties in The Station nightclub fire in West Warwick, Rhode Island on the night of Feb. 20, 2003. The investigation consisted of the following tasks:

- identification of technical issues and hypotheses requiring investigation through consultations with experts in fire protection engineering, and emergency evacuation, and members of other teams investigating The Station fire;
- data collection from local authorities, contractors and suppliers, building and fire protection design documents, records, plans, and specifications, video and photographic data, telephone and radio transmissions, field data, a limited number of interviews and other oral and written accounts from building occupants and emergency responders, and other witnesses as reported by the news media;
- analysis and comparison of model building and fire codes and practices, as well as review and analysis of practices used in operation of the building;
- simulation and analysis of phenomena (with associated uncertainties), including fire spread, smoke movement, tenability, occupant behavior and response, evacuation issues, and operation of active and passive fire protection systems;
- testing to provide additional data and support computer predictions; and
- preparation of the final report, following established NIST Editorial Review Board procedures, augmented by the NCST Advisory Committee.

As required by the NCST Act and its implementing regulations, priority in the investigation was ceded to the local criminal investigation. No physical evidence was obtained from the scene and access to witnesses and local authorities was limited due to the criminal investigations and civil litigation.

It should be noted that state and local building regulations -- rather than model codes -- govern building design, construction and operation. Comparisons of a building design and operation to provisions within model codes as part of the technical failure investigation by NIST have been done to enable an assessment of possible improvements in public safety through revision of model codes, standards and practices. The recommendations are directed toward the current national model codes maintained by the National Fire Protection Association (NFPA) and the International Code Council (ICC), the standards within those codes and elsewhere (e.g., ASTM International, and Underwriters Laboratories (UL)), and the practices associated with their adoption and implementation.

The NCST Act requires that at least one member of the Team be an employee of NIST, and that experts who are not employees of NIST shall also be appointed to the Team by the NIST Director. The members of the Team included the following:

- William Grosshandler (Lead Investigator), NIST Building and Fire Research Laboratory
- Nelson Bryner, NIST Building and Fire Research Laboratory

- Daniel Madrzykowski, NIST Building and Fire Research Laboratory
- Kenneth Kuntz, DHS/FEMA, US Fire Administration

Koffel Associates, Inc., provided a review of model building and fire codes; Ove Arup & Partners Massachusetts, Inc., assisted with the analysis of the evacuation process. Portions of both contractor reports have been integrated into this final report.

ACKNOWLEDGMENT

The number of people from NIST assisting the investigation extended beyond the official team members. Of particular note is Stephen Kerber, who devoted a tremendous amount of time and energy to running the fire simulations. The assistance provided by William Walton and Kevin McGrattan in this effort is also acknowledged. Erica Kuligowski was responsible for the egress simulations and was consulted regarding the behavior of humans in fire. The foam panel and full-scale mock-up experiments were ably supported by David Stroup, Laurean DeLauter, and Roy McLane.

Outside of NIST, the cooperation of the Bureau of Alcohol, Tobacco, and Firearms (Christopher Porreca in particular), and the assistance of the Army Research Laboratory (Steven Hoke) are acknowledged. Within the Department of Homeland Security, the Office of Domestic Preparedness coordinated their own investigation with NIST's work. The cooperation of the State of Rhode Island is acknowledged, in particular the Office of the State Fire Marshal and the Warwick field office of the Attorney General. WPRI-TV supplied the Team with the complete video taken on the night of the fire, and the *Providence Journal* provided NIST with information from their interviews with survivors of the incident.

EXECUTIVE SUMMARY

Note: This version of the report is a draft for public comment. NIST welcomes, in particular, any corrections of information in this draft, or any additional information that will improve the final report. NIST will consider all comments received by April 4, 2005, and will respond as it deems appropriate.

Comments can be sent via surface mail, facsimile, or e-mail as indicated below:

The Station Investigation
National Institute of Standards and Technology
100 Bureau Drive, Stop 8660
Gaithersburg, MD 20899-8660

Facsimile: (301) 975-4052
E-mail: NCST@nist.gov

An electronic version of the report and copies of the NIST videos are located on the NIST Web site:
http://www.nist.gov/ncst

Under the authority of the National Construction Safety Team Act, an investigation team was deployed by the NIST Director on Feb. 27, 2003 to investigate the failure seven days earlier of The Station nightclub in West Warwick, Rhode Island. The objectives of the investigation were the following:

- to establish the likely technical cause or causes of the building failure;
- to evaluate the technical aspects of evacuation and emergency response procedures;
- to recommend, as necessary, specific improvements to building standards, codes, and practices based on the findings made pursuant to the duties listed above; and
- to recommend any research and other appropriate actions needed to improve the structural safety of buildings, and improve evacuation and emergency response procedures, based upon the findings of the investigation.

The NIST team met these objectives primarily by reviewing and analyzing model building and fire codes, public documents, photographic and video data, telephone and radio transmissions, published accounts, and discussions with local authorities and several witnesses, by simulating and analyzing the fire spread, smoke movement, tenability, occupant behavior and response, and the impact of fire sprinklers, and by testing representative materials (not obtained from the site) to provide additional data and support the simulation predictions. The simulations and supporting fire tests were particularly important given that NIST was not able to obtain any physical evidence from the incident scene due to the ongoing criminal investigation and civil litigation. While the access to physical materials was denied to NIST, the Institute's investigators were provided extensive video tape footage taken before, during, and after the fire.

This report describes the methodology used to conduct the investigation, details what occurred on the night of Feb. 20, 2003, reviews the history of the building and the model codes and standards that would have applied to a building of this type, presents the results of testing and simulations, and includes recommendations to improve building safety, evacuation and emergency response procedures. It is important to note that state and local building regulations -- rather than model codes -- governed The

Station. NIST's comparison of the nightclub with model codes has been done strictly to enable an assessment of possible improvements in public safety through revision of codes, standards and practices. The recommendations are directed toward the current model codes maintained by the National Fire Protection Association (NFPA) and the International Code Council (ICC), the standards within those codes and elsewhere (e.g., ASTM International, and Underwriters Laboratories (UL)), and the practices associated with their adoption and implementation.

FINDINGS

The Station nightclub was a single-story wood frame building with a footprint of about 412 m^2 (4484 ft^2). The main entrance on the north side, with double doors, led to a short hallway with a single interior door. In addition to the main entrance, there were doors leading directly to the outside adjacent to the platform (commonly, but less precisely, referred to as the stage) on the west end of the building, and at the side of the main bar at the east end of the building. The kitchen also had an exit door. There were windows along the north side of the building on both sides of the main entrance.

The fire began when pyrotechnics used during the performance of a band ignited polyurethane foam lining portions of the walls and ceiling of the platform, and spread quickly along the ceiling area over the dance floor. Smoke was visible in the exit doorways in a little more than one minute and flames were observed breaking through a portion of the roof in less than five minutes. Egress from the nightclub was hampered by the crowding at the main entrance to the building. One hundred people lost their lives in the fire.

The most far-reaching findings from the investigation that had a direct bearing on the outcome of the incident are summarized here, grouped according to the materials and behavior of the fire, the building fire protection systems, the evacuation process, and the emergency response. Additional technical findings are presented in Chapter 8 of the report.

Materials

- A non-fire retarded foam sample purchased by NIST ignited within 10 seconds when exposed to a pyrotechnic device (15x15 gerb) in an arrangement similar to the set up on the platform of the nightclub. When a plywood panel with fire retarded polyurethane foam was exposed in a similar manner to a 15 x 15 gerb, no ignition of the panel occurred, nor did the plywood ignite with no foam present.
- As could be seen in the WPRI video, flames spread rapidly over the foam in the nightclub, generating smoke and enough heat (calculated to be almost 60 MW at its peak) to ignite the wood paneling underneath and adjacent to the foam. The wood paneling in the nightclub was estimated to contain over 95 percent of the fuel load, so that once most of the foam was consumed (estimated to be around two minutes after ignition of the foam), the fire transitioned to a wood frame building fire, with a steady heat release rate calculated to be around 45 MW.
- There was no fire resistant barrier between the interior of the nightclub and foam thermal insulation which had been installed in the stud space on the interior side of external walls of the drummer's alcove.

- In the reconstruction of the *platform area fire* conducted at NIST, within 90 seconds after ignition of the non-fire retarded polyurethane foam conditions near the middle of the dance floor at head height (1.5 m, or 5 ft, above the floor) were lethal.
- NIST could not obtain samples of the foam that actually had been applied to the nightclub walls to conduct a chemical analysis to determine if the polyurethane material contained fire retardants; however, the ignition behavior of the foam exhibited on the WPRI video was consistent with the behavior observed in the NIST testing with a non-fire retardant foam.

Fire Protection Systems

- Experiments conducted at NIST in a reconstruction of *the platform area* fire demonstrated that a water sprinkler system installed in the test room in accordance with NFPA 13 was able to control the fire initiated in non-fire retarded polyurethane foam panels and maintain tenable (survivable) conditions at head height in the test room for the duration (over five minutes) of the experiment. A computer simulation of the full nightclub with and without sprinklers led to a similar positive result for the sprinklered scenario.
- Automatic fire sprinklers were not installed in The Station nightclub, nor would they have been required for such existing structures under the 2003 editions of the model codes.
- A heat detection/fire alarm system was installed in The Station nightclub, which activated (sound and light strobe) 41 seconds after ignition of the polyurethane foam, by which time the crowd had already begun to move toward the exits.

Occupant Load and Egress

- The first patrons recognized the fire danger about 24 seconds after ignition of the foam; the bulk of the crowd began to evacuate shortly after that, around the time the band stopped playing (30 seconds).
- The rate of egress from the main entrance at the front of the building was limited by the single doorway inside the vestibule, not the double doors visible from the outside.
- About 2/3 of the occupants appear to have attempted to leave through the single main entrance in the front of the building; many were unsuccessful.
- Prior to 1-1/2 minutes into the fire, a crowd-crush occurred in the front vestibule which almost entirely disrupted the flow through the main exit. The precise event which led to the crowd-crush likely was related to the arrangement of the single interior door with merging streams of traffic and the pressure to escape the rapidly deteriorating conditions in the main area of the nightclub.
- Measurements of temperature, heat flux and gas species in a reconstruction of the platform area fire at NIST and computer models of the NIST experiment and the full nightclub suggest that the conditions around the platform, dance floor, sunroom, and dart room would have led to severe incapacitation or death within about 1-1/2 minutes after ignition of the foam for anyone remaining standing, and for not much longer even close to the floor.
- The number of building occupants at the time of the fire was reported by the Providence Journal to be 440; the occupant limit for a building similar to The Station nightclub would be 420 persons according to current model codes.

Emergency Response

- The first 911 call reporting a fire was before 11:09 p.m., less than 40 seconds after ignition of the foam; West Warwick police officers on the scene reported the fire about one minute after ignition of the foam, leading to the dispatch of four engine companies, a tower-ladder truck, a rescue unit, and a battalion chief .
- The first fire engine, staffed with one firefighter and a fire officer, was confirmed on-scene less than five minutes after the first 911 call was received, well within the limit of the NFPA standard for fire department response; however, NFPA standards recommend a minimum staffing level of four firefighters on both engine and truck companies, which was not achieved.
- A mass casualty plan was implemented capably within about 10 minutes of arrival of the first engine on the scene, such that within two hours of the start of the fire, all occupants needing medical attention had been evacuated from the scene and transported to medical facilities.

RECOMMENDATIONS

The findings presented above, and others that are documented in this report, raised a number of issues concerning model building codes and standards, and the practices surrounding their adoption, application, and enforcement. The specific sections of the current NFPA and ICC model codes that relate to these issues are identified in the report. The following twelve recommendations are made to improve model codes and standards, enhance fire safety and emergency response practices, and support research necessary to accomplish the improvements. Some significant actions already have been taken by the state of Rhode Island and the NFPA that incorporate aspects of the recommendations of this report, and these actions are described in the full report.

The first four recommendations should be applied in the model codes to all new and existing nightclubs regardless of size. The application to all existing nightclubs is a recognition that (i) the environment within The Station became lethal considerably sooner than 1-1/2 minutes, and (ii) the control of building contents, finish materials, and occupancy limits has been demonstrated to be considerably less rigorous in nightclubs (see Appendix C for multiple examples) than in most other places of assembly.

Recommendation 1

*NIST recommends that model codes require sprinkler systems for **all** new and existing nightclubs regardless of size, and that state and local authorities adopt this provision.*

Recommendation 2

In relation to the fire performance of finish materials and building contents, NIST recommends that model codes require, and that state and local authorities adopt the following provisions:

a) certain classes of materials (including non-fire retarded flexible polyurethane foam) that are known to easily ignite and rapidly propagate flames (i.e., they have an ignition temperature below some minimum, or a flame spread index and heat release rate greater than some maximum values) be clearly and specifically forbidden, with no exceptions, as finish materials from all new and existing nightclubs;

b) greater guidance be provided for when large-scale tests are required to demonstrate that materials do not pose an undue hazard for the use intended;

c) *the pass/fail criteria for flame spread tests and large-scale tests (including ASTM E-84, NFPA 255, and NFPA 286) be established using best measurement and prediction practices; and*

d) *strengthen provisions in NFPA 1126 (Use of Pyrotechnics before a Proximate Audience) which apply to all new and existing nightclubs through the following actions: banning the use of pyrotechnic devices from buildings less than 10,000 ft^2; requiring that all materials (including structural, finish, and contents) in structures that pyrotechnic devices are to be permitted meet low flame spread and heat release rate criteria , and require a minimum clearance greater than twice the designed projection of the device from the nearest fixed surface or moveable contents.*

Recommendation 3

*NIST recommends that the factor of safety on the time for occupants to egress from **all** new and existing nightclubs be increased in the model codes in the following manner, and that state and local authorities adopt these provisions:*

a) *Compute the number of required exits and the permitted occupant loads assuming at least one exit (other than the main entrance) will be inaccessible in an emergency evacuation.*

b) *Increase the capacity of the main entrance to accommodate, at a minimum, 2/3 of the maximum permitted occupant level during an emergency.*

c) *Eliminate trade-offs between sprinkler installation and factors that impact the time to evacuate buildings.*

d) *Require staff training and evacuation plans for buildings that cannot be evacuated in less than 1-1/2 minutes.*

e) *Provide improved means for occupants to locate emergency routes -- such as exit signs near the floor and floor lighting -- once standard exit signs become obscured by smoke.*

f) *Establish the threshold building area and occupant limits for egress provisions using best practices for estimating tenability and evacuation time.*

g) *Require explicit evacuation directions be provided to occupants prior to the start of any public event inside a structure used for public assembly.*

Recommendation 4

NIST recommends that model building and fire codes require, and that state and local authorities adopt, the application of new life-safety provisions to existing as well as new nightclubs, and that the practice of grandfathering older structures be eliminated. Exemptions from the new provisions should be on a case-by-case basis and justified by a comprehensive fire safety analysis using best practices.

Recommendation 5

NIST recommends that model codes and standards require redundancy in the passive and active fire protection systems to ensure adequate performance of the structure when one or more of the protective systems is compromised by uncertain behaviors of the building owner or occupants such as the following:

a) installing building decorations or temporary features that greatly exceed flame spread or fire load provisions;

b) exposing the building to strong ignition sources;

c) exceeding the posted occupancy limits;

d) temporarily blocking an exit; and

e) *disabling sprinklers or other life safety systems for maintenance.*

Recommendation 6

NIST recommends that when performing an analysis of proposed changes to model building and fire codes, proper account should be taken of the soundness of and safety factor provided by the existing provisions in light of the history of similar building failures.

Recommendation 7

NIST recommends that the model codes increase the number of portable fire extinguishers required, with their number and placement based upon a minimum time for access and application in a fully occupied building, and that staff be properly trained in their use.

Even though the first fire engine arrived expeditiously, the speed at which the fire engulfed The Station rendered it impossible for the fire department to save the structure or the lives of many victims. However, the importance of the role of fire prevention activities in avoiding a future tragedy was highlighted by this incident. As in all mass causality events, especially those where the window of opportunity for rescue is extremely limited, effective and efficient communications within and among the various responding agencies is imperative. Developing effective interoperable communications requires addressing numerous critical success factors, including frequent use of interoperable communications equipment and procedures, formal governance and collaboration, formal standard operating procedures, appropriate technology, and multiagency training and exercises. Tools and best practice models addressing many of these success factors, including a statewide communications interoperability planning methodology are available though the Department of Homeland Security's SAFECOM Program.

Recommendation 8

NIST recommends that the model codes provide specific guidance on how to implement an effective fire inspection program, including the training necessary to implement it, and that state and local authorities adopt such guidance in practice. Items to consider include the following:

a) documentation of building permits and alterations;

b) means of egress inspection and record-keeping;

c) frequency and rigor of fire inspections, including follow-up and auditing procedures;

d) education and training of inspectors and owner; and

e) guidelines on recourse available to the inspector for identified deviations from code provisions .

Recommendation 9

NIST recommends that

a) career and volunteer fire departments comply with the minimum apparatus staffing such as those suggested in NFPA Standards 1710 and 1720, respectively, and NFPA 1500 as appropriate;

b) public safety agencies at all levels give greater attention to the difficulty of communications systems interoperability, and that fire service and emergency medical services organizations make every effort to assure they develop and maintain sufficiently robust, interoperable communications capabilities to support major incident operations, including those requiring substantial mutual aid augmentations, such as those suggested in NFPA Standard 1221; and

c) major incident/mass casualty operations be conducted utilizing appropriate Incident Command/Unified Command structures, policies and practices such as those suggested in NFPA Standard 1561.

NIST is required, under the NCST Act, to identify areas of research needed to support improvements to model building codes, standards and practices. Based upon the findings of this investigation and the resultant recommendations presented above, additional research is recommended in three general areas: human behavior and people movement, material behavior and fire spread, and decision aids.

Recommendation 10

NIST recommends that research be conducted to better understand human behavior in emergency situations, and to predict the impact of building design on safe egress in fires and other emergencies (real or perceived), including the following:

a) the impact of fire products (gases, heat, and obscuration) on occupant decisions and egress speeds;

b) exit number, placement, size and signage;

c) conditions leading to and mitigating crowd crush;

d) the role of crowd managers and group interactions;

e) theoretical models of group behavior in emergency situations suitable for coupling to fire and smoke movement simulations; and

f) the level of safety that model codes afford occupants of buildings.

Recommendation 11

NIST recommends that research be conducted to understand fire spread and suppression better in order to provide the tools needed by the design profession to address recommendations 1 through 10 above. The following specific capabilities require research:

a) prediction of flame spread over <u>actual</u> wall, ceiling and floor lining materials, and room furnishings;

b) <u>quantification</u> of smoke and toxic gas production in realistic room fires; and

c) development of generalized models for fire suppression with fixed sprinklers and for firefighter hose streams.

Recommendation 12

NIST recommends that research be conducted to:

a) refine computer-aided decision tools for determining the costs and benefits of alternative code changes and fire safety technologies, and

b) develop computer models to assist communities in allocating resources (money and staff) to ensure that their response to an emergency with a large number of casualties is effective.